Muon g-2 Straw Drift Chamber Tracking Detectors

Danny Rosseau

August 9, 2013

Abstract

To minimize systematic error associated with the momentum and spatial distribution of the muon beam, Fermilab's Muon g-2 Experiment, E989, plans to implement straw drift chamber detectors which will provide a means of tracking the positron (or electron) resulting from the muon decay and trace its trajectory back to find out where it decayed. The tracking detectors also offer an opportunity to make measurements of a possible electric dipole moment by measuring how much the resulting positron (electron) moves vertically. The preliminary data aquisition system is also discussed.

I. INTRODUCTION

The new muon g-2 experiment at Fermilab aims to measure the anomalous magnetic moment of the muon, a_μ, to an unprecedented precision of of 0.14 ppm (parts per million)[1]. This is almost a fourfold improvement in uncertainty over the previous measurement at Brookhaven National Lab's g-2 experiment, which was 0.54 ppm[2]. Along with measuring a_μ the experiment should be able to put further constraints on a possible electric dipole moment of the muon, d_μ. Both the measurement of a_μ and d_μ will provide precise tests of the standard model and possibly reveal new physics beyond the standard model.

In order to minimize systemic error in the measurements, straw drift chamber tracking detectors are placed in front of some of the main detectors to monitor the muon beam. The detectors allow us to recreate the trajectory of the emitted positron (or electron)[1] back to the point where the muon decay occured, giving detailed information on momentum and position distribution of the beam. This information must be convoluted with the magnetic field map to get a better idea of the actual magnetic field seen by the decaying muon.

[1] The muons will primarily decay according to $\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$ and $\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$

II. THEORETICAL BACKGROUND

To compute a value for a_μ two frequencies are measured, ω_a, the rate at which the muon polarization turns relative to the momentum, and ω_p, the value of the magnetic field normalized to the Larmor frequency of a free proton. It can be shown[1] that, in the presence of electric and magnetic fields,

$$\vec{\omega}_a = -\frac{Qe}{m}\left[a_\mu \vec{B} - a_\mu \left(\frac{\gamma}{\gamma+1}\right)\left(\vec{\beta}\cdot\vec{B}\right)\vec{\beta} - \left(a_\mu - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right] \tag{1}$$

This equation is only missing the negligible contribution from the potential electric dipole moment of the muon. In order to make this equation a little more useable, we normally work with muons at the "magic momentum"[1], corresponding to $p \approx 3.094$ GeV, or $\gamma = 29.3$, which removes the motional electric field term. Then, as long as $\vec{\beta}\cdot\vec{B} = 0$, the equation takes the much simpler form of

$$\vec{\omega}_a = -a_\mu \frac{QeB}{m} \tag{2}$$

The magnetic field is then remove from this equation by using a ratio with the Larmor frequency of a free proton, ω_p measured using NMR[1] during the experiment. The final idealized equation used to calculate a_μ then after some algebra and using fundamental constants is,

$$a_\mu = \frac{\omega_a/\omega_p}{\mu_{\mu^+}/\mu_p - \omega_a/\omega_p} \tag{3}$$

with μ_{μ^+}/μ_p being known to 27 ppb[1].

The focus of this paper is on the detectors built to deal with the case when $p \neq p_{magic}$ or $\vec{\beta}\cdot\vec{B} \neq 0$, which will be common enough cases that they need to be dealt with to acheive the desired 0.14 ppm precision.

III. TRACKING DETECTORS

The method for handing the cases mentioned above requires collecting information about the muon beam that allows us to modify the measurements of ω_a to get better results. Tracking detectors will fullfill that goal, on top of also providing a method to possibly detect the permanent electric dipole moment.

A. DRIFT CHAMBERS

Drift chambers are used in particle physics experiments to get precise locations of particles. A simple drift chamber consists of a wire held at a positive high potential inside of a gas contained in a grounded outer shell. These are called "straw" drift chambers and are the type that will be used for g-2. When a charged particle passes through the gas it will ionize gas particles along its trajectory. The newly formed ions and free electrons will move in accordance with the strong electric field inside of the straw, with the ions moving away from the wire and the elctrons moving towards it. As the electrons move closer and closer to the wire their kinetic energy increases rapidly and they too can start to cause ionization of the gas particles. This creates an avalanche effect very close to the wire, causing a large enough signal to be created and detected by readout electronics.

Multiple straws need to be used for detection due to the circular symmetry of the drift chamber. A single straw is only able to place a particle's path on a circle centered on the wire of some radius, using multiple straws removes this issue as long as they are staggered as in Figure 1.

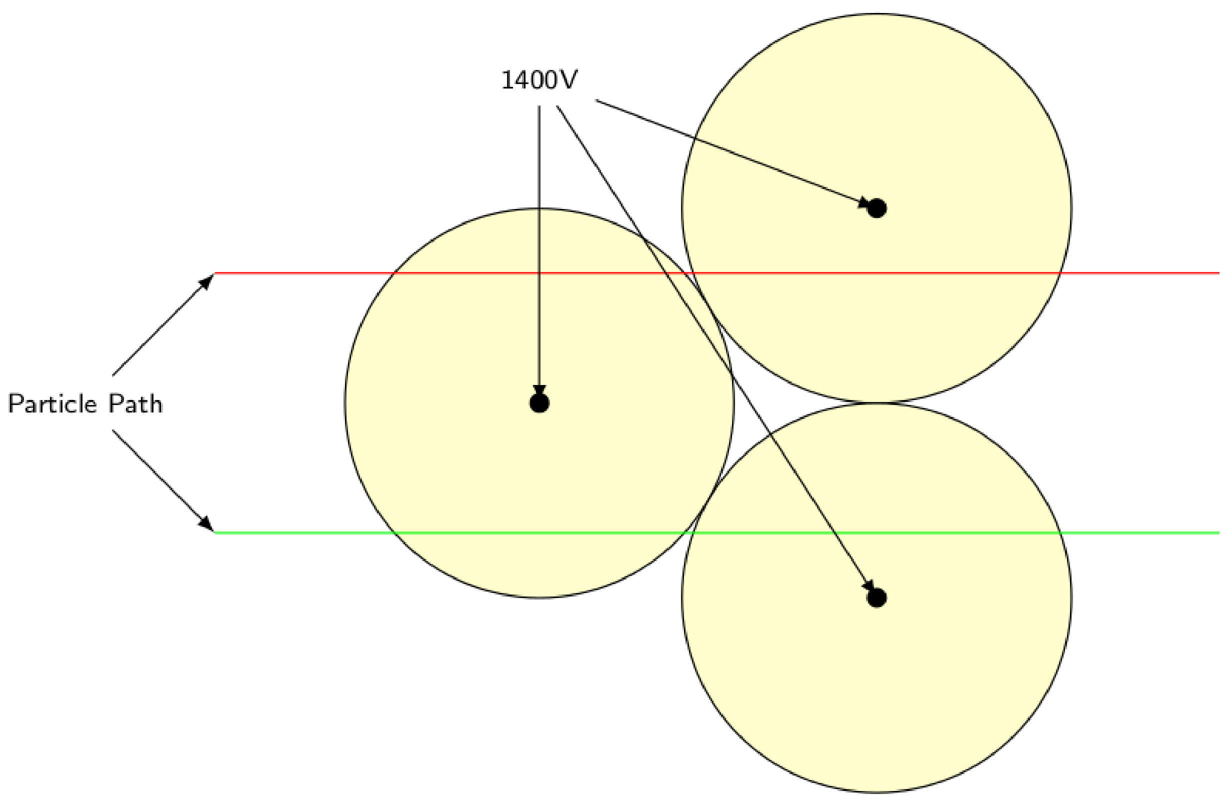

Figure 1: Two potential particle paths that would give the same location if there was only one straw but are unambiguous with more than one and staggering

B. IMPLEMENTATION

The tracking detectors will be placed at two locations along the g-2 ring as shown in Figure 2. They will consist of arrays of straw tubes with alternating planes oriented 7.5° from the vertical. A simple drawing of a 24 straw tracking station can be seen in Figure 3. There will be a total of 2432 straws used for the two locations, the stations are laid out as in Figure 4.

The straws will be filled with a gas composed of 80% Ar and 20% CO_2 and placed inside of the vacuum. Each station has its own custom made readout electronics which are designed to route the signals produced by the avalanche to ECL ports on TDC's, which are the first stop on the data acquisition line.

I ran simulations using CERN's Garfield[8] software to test different parameters and how they affect the resolution of the straws. Parameters checked included, voltage of the central wire, magnetic field strength, and wire offset from center.

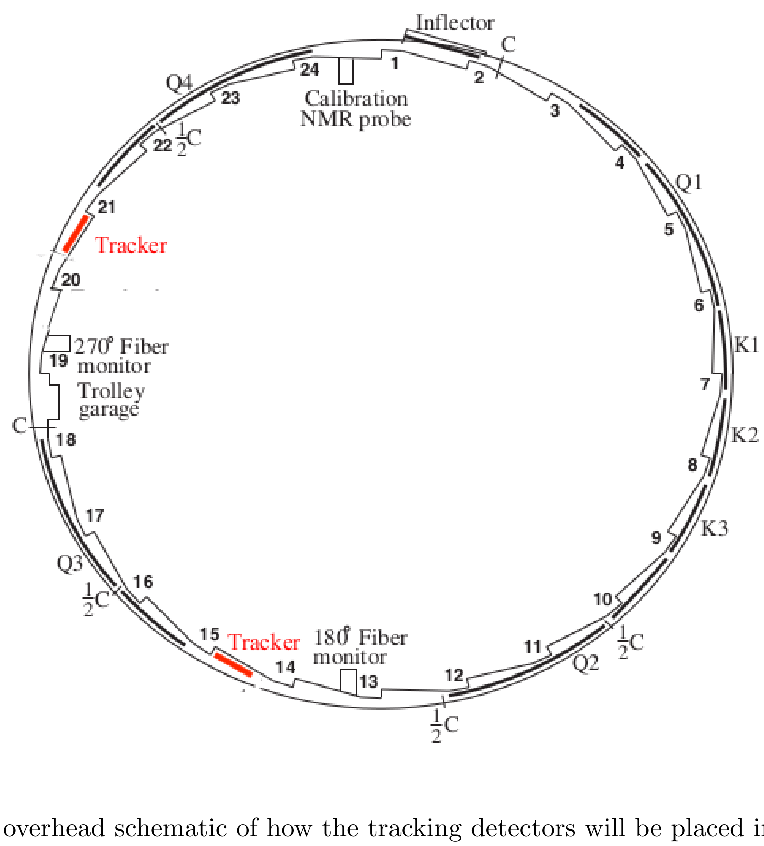

Figure 2: An overhead schematic of how the tracking detectors will be placed in the main ring

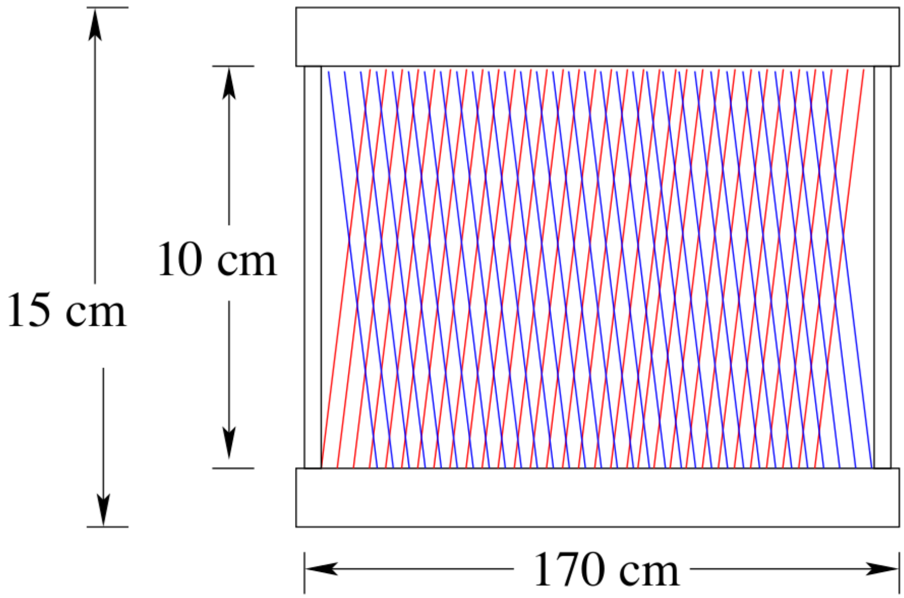

Figure 3: A tracking station that is 24 straws wide, notice the angle

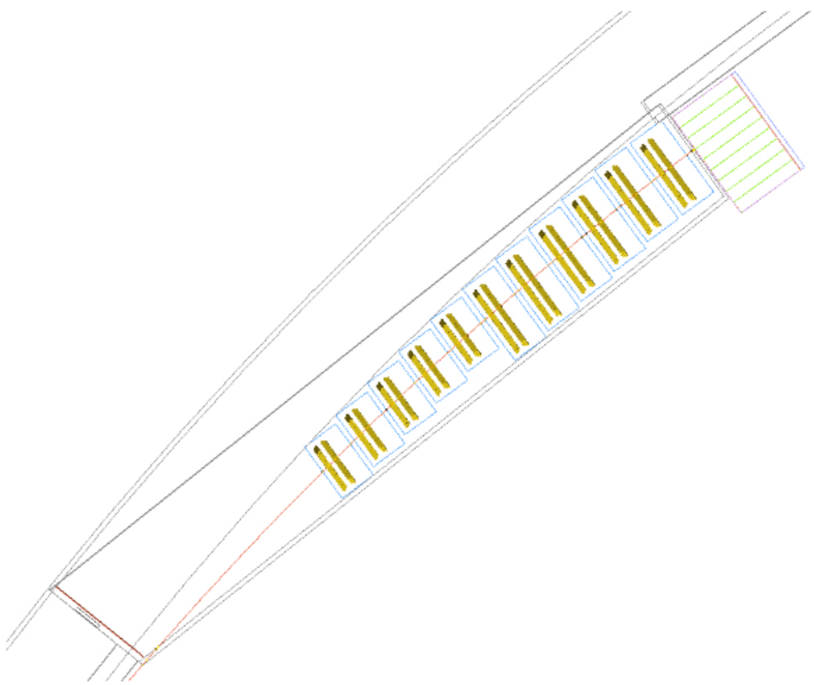

Figure 4: A close up view of an arm containing the straw detector stations

IV. DATA ACQUISITION SYSTEM

The tracking detector's data acquisition system (DAQ) plans to make use of the MIDAS[3] and ROOT[4] software in conjunction with CAMAC crates containing LeCroy 3377[5] TDC's and a Jorway 73A CAMAC Crate Controller[6].

The MIDAS software package was developed specifically for experiments in particle physics and allows for control over the experimental parameters online, including slow control systems and monitoring of data. It provides C libraries for reading out the electronics with a frontend machine and sending them down the line to an analyzer. The analyzer in this case is written in C++ using Triumf's ROOTANA[7] to read events from MIDAS buffers for further processing and storage.

When a positron (electron) passes through one of the straws, the cascade will cause a signal on the wires which will be read by the TDC's. If the change surpasses a set threshold the TDC will signal to the crate controller that it has an event ready to be read out. The crate controller will read that event and send it, along with a header word containing information about the TDC's settings, to the MIDAS frontend. The frontend will then store that event in a shared memory buffer to be accessed later by the analyzer as well as saving the event in a bank to later be saved as a backup. The analyzer can read the data in real time or access the backup data file, decode it into a time measurement, and then process it further as needed.

My efforts were focused on getting this DAQ up and running in a preliminary form to test the feasability of using them for the experiment. I needed to rewrite much of the driver provided for the Jorway 73A to make it properly interact with MIDAS and create a frontend and analyzer to feed fake data into for testing. The data was treated as if it were a signal from the straws themselves and analyzed as such. I also wrote a C++ class to deal with the decoding of data sent from the crate.

V. ACKNOWLEDGEMENTS

I would like to thank Fermilab for giving me the opportunity to work on such a great project and also my mentor.

VI. REFERENCES

Putting the actual citations in when I get them all collected

1 g-2 CDR

2 G.W. Bennett, et al., Phys. Rev. D 80, 052008 (2009).

3 https://midas.psi.ch/

4 http://root.cern.ch/ 5 http://www-esd.fnal.gov/esd/catalog/main/lcrynim/3377man.pdf

6 http://www-esd.fnal.gov/esd/catalog/main/jorway/73A˙User˙Guide.pdf

7 http://ladd00.triumf.ca/ olchansk/rootana/

8 http://garfield.web.cern.ch/garfield/